Liquid plasma produced by intense laser light

Norio Tsuda and Jun Yamada
Dept. of Electronics, Aichi Institute of Technology
1247, Yachigusa, Yakusa, Toyota, 470-0392 Japan

The plasma produced in liquid by the excimer and YAG laser light is studied and the basic data about breakdown threshold of liquid and the development behavior of plasma are examined.

1. Introduction

When the laser light is focused at the solid or gas, a hot and dense plasma is produced.[1～7] However, the laser induced plasma in liquid hasn't been studied enough. When a laser light is focused in liquid, a hot plasma is produced at the focal spot. The mechanisms of the breakdown and the plasma development have not almost been investigated. In liquid, the laser induced plasma may be able to resolve the hazardous material called the environment material, or the plasma produced in a physiological saline may become to be the basic data when the human body is irradiated by the laser light. Then, plasma produced in liquid by the laser light is studied and the basic data about breakdown threshold of liquid and the development behavior of plasma are examined.

2. Experimental arrangement

The experiment arrangement is shown in Fig. 1. Excimer or YAG laser light is focused in liquid. The maximum laser power of excimer laser is 500 mJ with a wavelength of 308 nm and a pulse half width of 30 ns. While the maximum laser power of YAG laser is 340 mJ with a wavelength of 1064 nm and a pulse half width of 15 ns. Moreover, the YAG laser is able to drive the second harmonic oscillation with a power of 180 mJ, a wavelength of 532 nm and a pulse half width of 15 ns. The YAG laser is operated at the wavelength of 532 nm. The chamber is made of acrylic and has three quarts glass windows of height of 25 mm, width of 30 mm and thickness of 2 mm. The ultra pure water or the ultra pure water with a melted NaCl is used as a test liquid. The excimer laser is focused using the concave mirror to avoid influence of refraction at liquid surface. The backside of acrylic chamber is able to attach the concave mirror. The diameter of the focal spot is 96 μm when the laser light is focused using the concave mirror of focal length 25.4 mm. On the other hand, the YAG laser light is focused from the out side of the chamber using the lens of the focal length 60 mm, because the intensity of YAG laser light is so high that the concave mirror can not be used. The diameter of focal spot is 130 μm. The laser power is controlled using the optical filter.

To examine the attenuation of laser light in liquid, the photodiodes are set up at back and front of the chamber. The transmittance is measured from the ratio of transmitted laser power to the incident one.

When NaCl concentration is varied, the threshold value of light intensity is measured taking into account the absorption of laser light in liquid. The threshold laser intensity is defined as an intensity at which the plasma production probability is 50 %.

The plasma development is observed using the streak camera. The plasma luminosity is focused on the incident slit of the streak camera by relay lens with a focal length of 100 mm. The streak image is displayed on a monitor by a dummy color of light intensity. The plasma boundary is determined by a threshold intensity because the plasma boundary of the streak image is not so clear. The plasma boundary is drawn by a plotter.

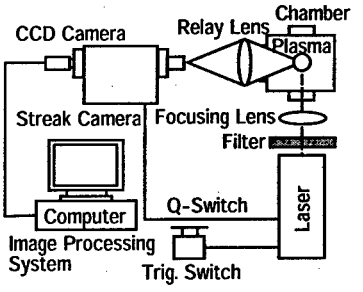

Fig. 1. Experimental arrangement.

3. Experimental results

3.1 Transmittance

The transmittance of the laser light through NaCl solution is measured. The transmittance as a function of NaCl concentration is shown in Fig. 2. When the excimer laser is used, the transmittance decreases with increasing concentration. The attenuation of laser light in NaCl solution is not negligible because NaCl molecular absorbs the laser light. However, the transmittance of YAG laser is 40 %, which is almost a constant independent on NaCl concentration. The scattering loss of YAG laser light may be so large that the transmittance turns out large because the temporal coherent of YAG laser is better than one of excimer laser.

3.2 Threshold characteristic

When NaCl solution is irradiated by the laser light with the intensity near threshold, we watch whether the plasma is produced or not. From 20 observations, a plasma production probability is examined. The threshold characteristic for NaCl concentration using

excimer laser or YAG laser is shown in Fig. 3. The threshold intensity of plasma produced by YAG laser is lower than that by the excimer laser, because the spot size and the absorption coefficient of YAG laser are bigger than those of the excimer laser. The threshold values decrease with increasing NaCl concentration because the ionization coefficient increases with increasing the NaCl concentration. If the NaCl concentration increases moreover, the threshold value may increase again because the collision occurs more frequently with increasing NaCl concentration.

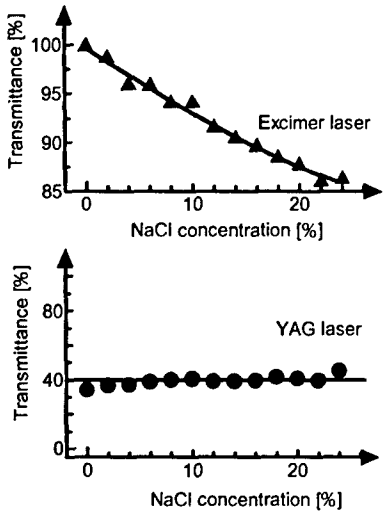

Fig 2. Transmittance.

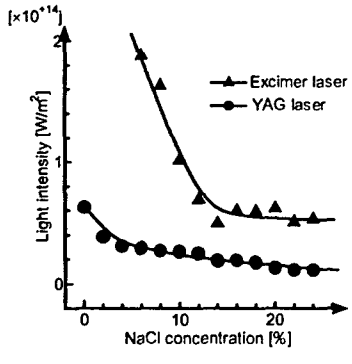

Fig. 3. Threshold characteristic.

3.3 Streak image

The typical streak image of the plasma, which is produced by YAG laser, is shown in left figure of Fig. 4. The laser light is irradiated from the right hand side, the time is scanned from top to bottom, and the inside of the boundary shows the plasma. The YAG laser is operated at 1064 nm. The plasma produced in liquid develops only backward because the plasma frequency is higher than the laser frequency and laser light is absorbed at only backward plasma surface. The plasma consists of a group of plasmas produced from many seeds because the electrolytes in liquid as seed may initiate the plasma production.

On the other hand, the plasma produced by the excimer laser is produced at the focal spot and develops backward and forward asymmetrically as shown in right figure of Fig. 4. The development mechanism of forward plasma is different from that of backward plasma. When the concentration of sodium chloride is higher, the plasma develops forward widely. However, when the concentration is too high, the plasma develops hardly because the laser light is absorbed in liquid.

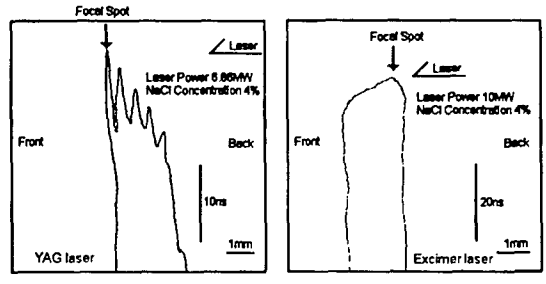

Fig. 4. Streak image.

4. Conclusion

When the liquid is irradiated by the ultraviolet laser light or visible laser light, the plasma is produced at the focal spot. The characteristic of transmittance is different when the YAG laser or excimer laser is used. The transmittance of excimer laser light decreases with increasing the NaCl density. However, the transmittance of YAG laser light is a constant. Threshold intensity decreases with increasing NaCl concentration. Threshold intensity of plasma produced by YAG laser is lower than that by excimer laser, because the focal spot size of YAG laser is bigger than that of the excimer laser. The dynamic behavior of the laser produced plasma is observed by the streak camera. The plasma produced by excimer laser develops not only backward but also forward. However, The plasma produced by YAG laser develops only backward.

5. References

[1] R.G. Meyerand, and A.F.Haught, Phys.Rev.Lett. **11** (1963) 401.

[2] Yu.P.Raizer, Sov.Phys.JETP, **21** (1965) 1009.

[3] G.V.Ostrovskaya, and A.N.Zaidel', Sov.Phys.Usp, **16** (1974) 834.

[4] J.Yamada, and T.Okuda, Jpn.J.Phys, **18** (1979) 139.

[5] J.Yamada, and T.Okuda, Laser Particle Beams, **7** (1989) 531.

[6] J.Yamada, N.Tsuda, Y.Uchida, H.Huruhashi, and T.Sahashi, Trans. IEE Jpn, **114** (1994) 303.

[7] N.Tsuda, and J.Yamada, J.App.Phy, **81** (1997) 582.